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UTILIZATION OF BACKFILL SUPPORT IN LONGITUDINAL CUT-AND-FILL MINING

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by

D.G.F. Hedley*

ABSTRACT

Backfill is a passive support system that has to be compressed before exerting a reaction. The magnitude of the reaction is dependent on the deformation modulus of the fill and the amount of convergence it is subjected to. This latter aspect depends on when fill is placed in the mining sequence.

Two methods of overhand longitudinal cut-and-fill are compared: vertical drilling (uppers), where backfilling lags behind mining by one cut; and horizontal drilling (breasting), where backfill is poured within 1 m of the back prior to blasting the cut. For stope spans of 39 m, it was found from theoretical models that 46% of the total convergence is utilized in compressing the backfill in uppers cut-and-fill, compared to 60% in breasting cut-and-fill.

Backfill also absorbs energy that otherwise would be released as seismic energy. For a typical mine backfill, 23% of the energy released is absorbed in breasting cut-and-fill, compared to 15% in uppers cut-and-fill.

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UTILISATION DU REMBLAYAGE COMME SOUTÈNEMENT DANS LA MÉTHODE D'ABATTAGE PAR CHAMBRES REMBLAYÉES

par

D.G.F. Hedley*

RÉSUMÉ

Le remblayage est un système de soutènement passif qui doit être comprimé avant de produire une réaction. L'ampleur de la réaction est fonction du coefficient de déformation du remblai et de l'importance de la convergence dont il est l'objet. Ce dernier aspect est fonction du moment où se produit l'opération de remblayage dans les travaux d'extraction minière.

Dans ce rapport on compare deux techniques d'exploitation par la méthode d'abattage en gradins pour l'exploitation par chambres remblayées longitudinales: le forage vertical, où le remblayage fait suite au déblayage après l'extraction minière et le forage horizontal (abattage de front) qui préconise le versement du remblai dans les limites de 1 m de l'entaille avant le dynamitage du déblai. Au moyen de modèles théoriques, on a découvert que par la méthode d'abattage vertical par chambres remblayées 46% de la convergence totale d'un remblai d'une envergure de 39 m sert à la compression du remblai comparativement à 60% par la méthode d'abattage de front par chambres remblayées.

Le remblai absorbe l'énergie qui autrement serait libérée sous forme d'énergie sismique. Au cours d'un remblayage typique, 23% de l'énergie libérée est absorbée avec la méthode d'abattage de front par chambres remblayées par rapport à 15% avec la méthode d'abattage vertical par chambres remblayées.

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INTRODUCTION

Backfill is used in many mining methods, either concurrently with stoping, as in longitudinal and transverse cut-and-fill, or delayed at the completion of stoping, as in blasthole and vertical retreat methods. The functions of backfill can be seen as providing regional support, pillar support, an artificial roof, a working floor, dilution control and disposal of a waste product (1). In addition backfill will absorb energy which is released as a result of mining (2).

In recent years CANMET has been doing research on the optimization of backfill from a size distribution and cement content viewpoint (3). It has been found, for both sand and rock types of fill, that there is an optimum mix of product sizes that for a certain cement content will provide a maximum fill stiffness or deformation modulus (4). However, besides the support characteristics of the backfill its time of placement in the mining sequence is also important.

Other than its own body weight, backfill is a passive support system in that it has to be compressed before exerting a reaction force against the rock mass. Compression results from expansion or convergence of the wall rocks. If fill placement is delayed then part of the convergence will have already occurred and the maximum fill support capacity will have been lost irrespective of its stiffness characteristics. Compared to an unfilled stope, backfill will reduce the volumetric convergence of the stope walls, decrease the stress concentration on the rock abutments, increase the strength of the wall rocks by its restraining effect and absorb energy, thereby decreasing the energy released as kinetic or seismic energy. Some of these effects will be small, unless the stope is at great depth (i.e., 2000 m) or the backfill is very stiff (i.e., 2 GPa). However, it is constructive to compare how much of the

convergence is theoretically utilized in compressing any type of backfill and how much energy is absorbed for different stoping methods.

As an example, two methods of overhand longitudinal cut-and-fill, Fig. 1, are compared. In the first method 'uppers' or near vertical drilling is employed and backfilling lags behind stope advance by one cut, so that distance between backfill floor and stope back varies from one to two cuts. In the second method 'breasting' or horizontal drilling is employed with so called 'tight' backfilling. In this case backfill is poured to within 1 m of the stope back (to allow for expansion of the blasted rock) before the next cut is blasted.

A single stope 3 m wide dipping at 70° at a depth of 1000 m is analyzed. Thirteen cuts of 3 m high are taken to give a total stope span of 39 m on dip. It is assumed that the stope length on strike is large so that the stresses and displacements can be calculated in a 2-dimensional cross-section.

CONVERGENCE OF AN ISOLATED STOPE

There are many two-dimensional computer programs which can be used to calculate the stresses and displacements around a single opening in a homogeneous elastic medium. However, for this simple example the basic equations can also be used which has the additional benefit of identifying the parameters which affect the results.

If the stope is considered as a thin slot with rigid abutments then the convergence distribution across the slot can be expressed by (5):

$$S = \frac{4(1 - \nu^2)So}{E} \left(1 + \frac{cx}{2}\right)\sqrt{a^2 - x^2} \qquad \text{Eq 1}$$

where, S = convergence

ν = Poisson's ratio

So = virgin stress perpendicular to the orebody

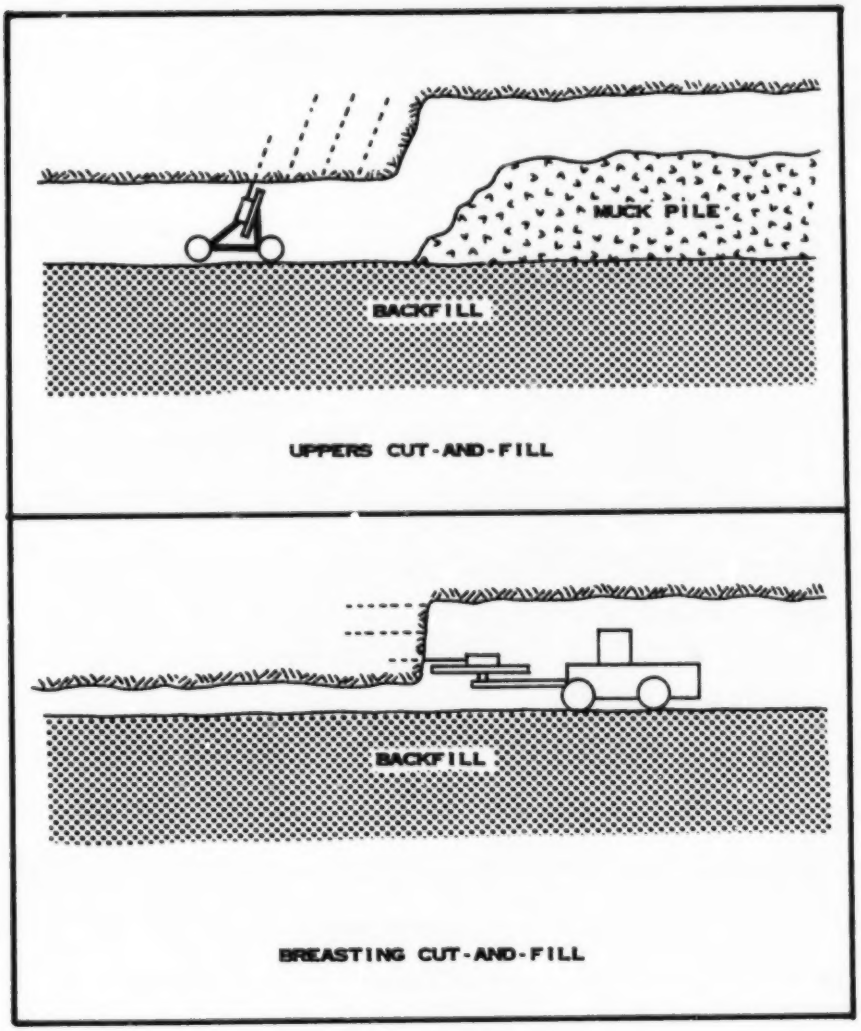

Fig. 1 - Uppers and breasting cut-and-fill techniques.

a = half span

x = distance from centre of span ($-a \leq x \leq a$)

$c = \frac{\sin\alpha}{H}$, α = dip angle, H = depth below surface.

Assuming that the principal stresses are vertical and horizontal, the perpendicular virgin stress is obtained from:

$$So = \frac{\gamma H}{2}[(1 + k) + (1 - k) \cos 2\alpha] \qquad \text{Eq 2}$$

where, γ = unit weight of the rock mass

k = ratio of the horizontal to vertical virgin stress.

In the calculations the following values were chosen to represent typical hardrock mines in the Canadian Shield.

$\nu = 0.20$ $\qquad$ E = 70 GPa

$\gamma = 0.027\ MN/m^3$ $\qquad$ k = 2.0

In Equation 1 the term $\frac{'cx'}{2}$ takes into account the variation in the virgin perpendicular stress on either side of the centre line. At a depth of 1000 m, unless the stope span is large, the term is insignificant. Maximum convergence occurs near the centre of the span and equals:

$$S_{max} = \frac{4(1 - \nu^2)So\ a}{E} \qquad \text{Eq 3}$$

which indicates that So, a and E are the important parameters affecting the magnitude of the convergence. It will be noticed that the stope width does not enter Equations 1 or 3 because of the assumption that the abutments are rigid. In actual practice, the rock abutments at the top and bottom of the stope will be compressed a small amount and this compression is dependent on stope width and will increase the total convergence.

The convergence profiles for each of the 13 cuts are shown in Fig. 2(a) and 2(b). The shaded areas indicate the proportion of the convergence utilized in compressing the backfill in 'uppers' cut-and-fill, Fig. 2(a), and

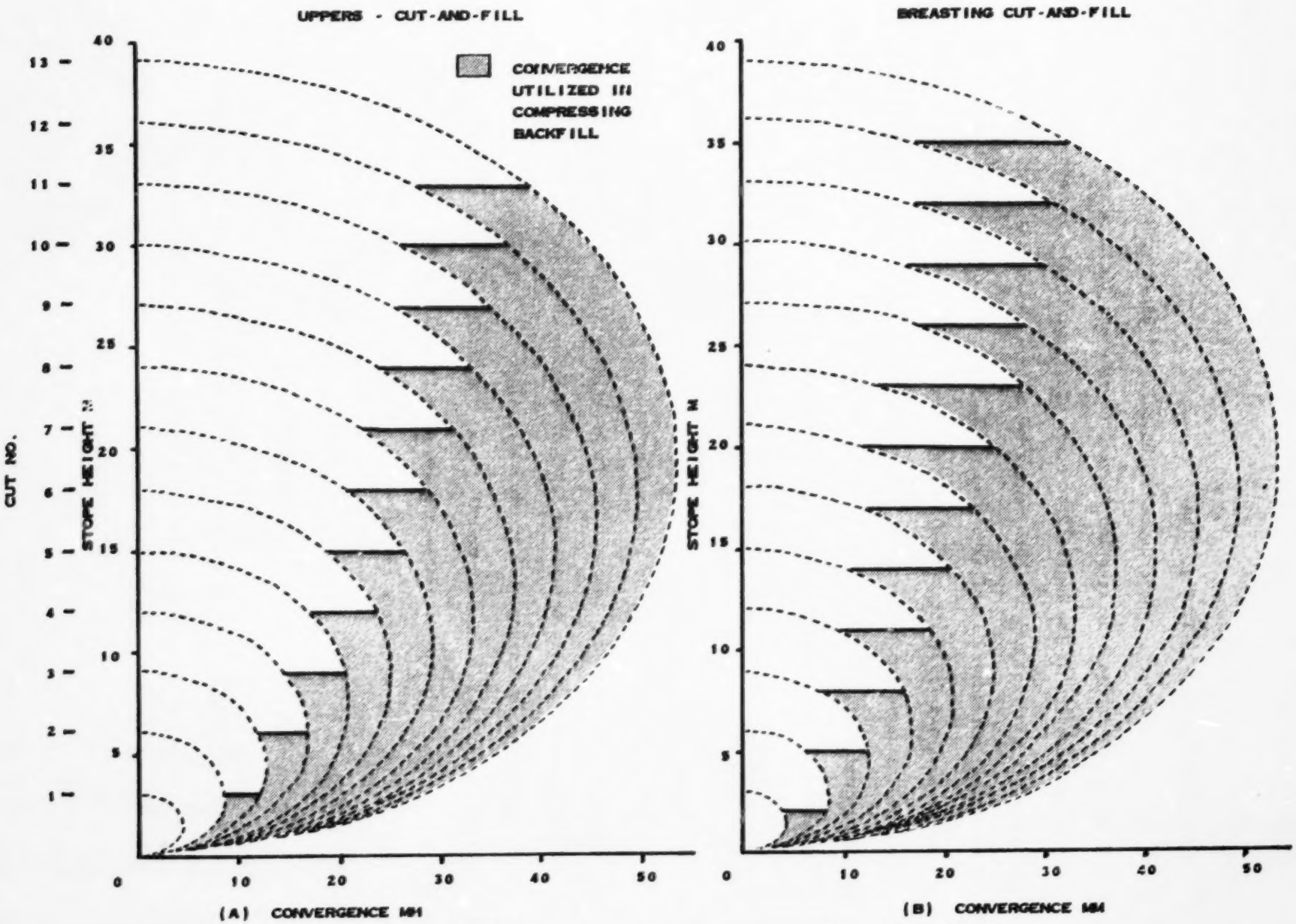

Fig. 2 - Utilization of convergence in compression of backfill.

'breasting' cut-and-fill, Fig. 2(b).

The volumetric convergence of the backfill after each cut can be calculated by integrating Equation 1 over the relevant limits of 'x'. Volumetric compression of the backfill as a percentage of total volumetric convergence after each cut and for both mining methods is shown in Fig. 3. Clearly, 'breasting' cut-and-fill utilizes more of the available convergence than 'uppers' cut-and-fill, after the 13th cut being 60% and 46%, respectively. This 30% relative improvement for 'breasting' cut-and-fill would suggest that ground conditions should also be better than in 'uppers' cut-and-fill stopes. The option does exist of starting a stope with 'uppers' cut-and-fill then converting to 'breasting'. Figure 3 shows the result of such a conversion after the 10th cut which results in a 10% relative improvement in backfill utilization after the 13th cut.

In this analysis the interaction between the backfill and the wall rocks has been ignored. In practice the backfill will resist the convergence of the stope walls, but unless the depth is great or the backfill stiffness very large the inaccuracy will be minimal. Also only the elastic displacements have been considered and rock normally has some inelastic characteristics. However, the inelastic displacements are also probably proportional to stope span so that the percentage comparisons in Fig. 3 are still probably valid for inelastic conditions.

ENERGY BALANCE

As a result of mining, stresses are redistributed and displacements occur. Consequently, energy enters the system and has to be disposed of. The basic energy balance can be expressed by (2):

$$W_t + U_m = U_c + W_r \qquad \text{Eq 4}$$

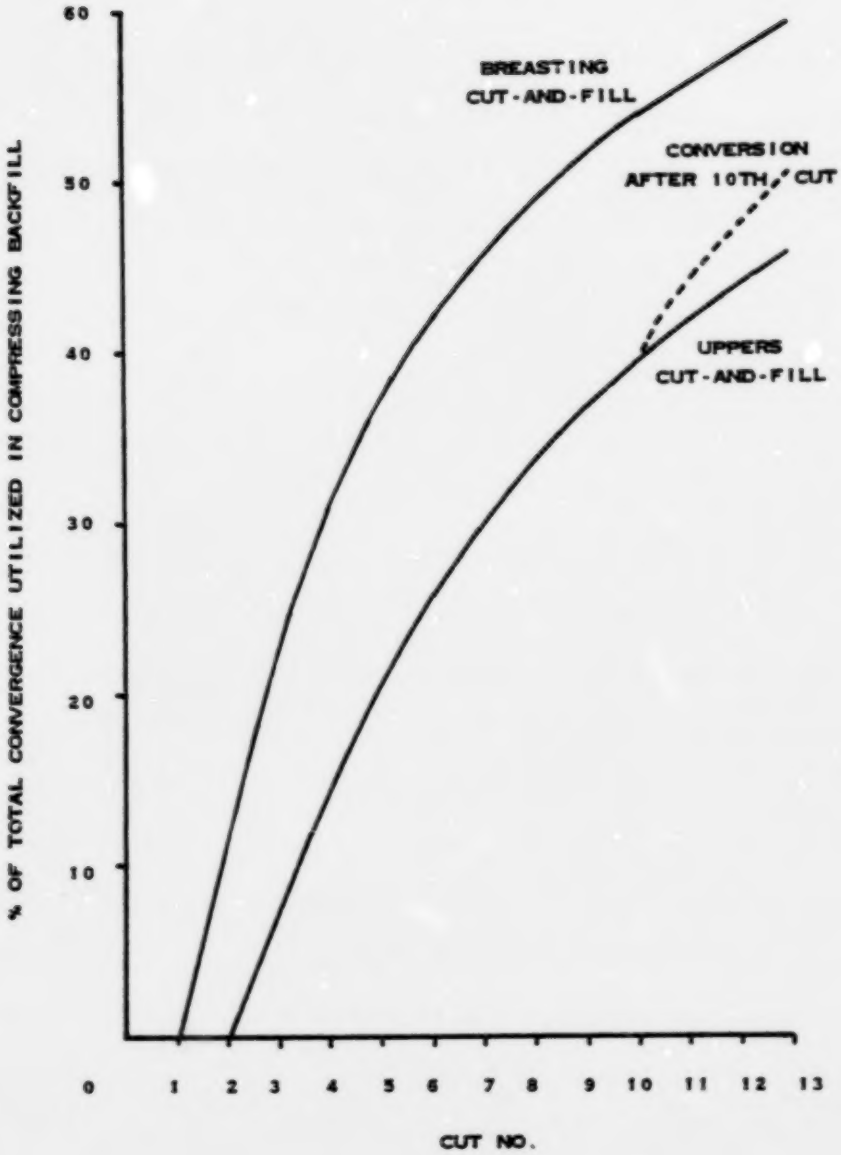

Fig. 3 - Percentage utilization of convergence in compressing backfill.

where, W_t = change in potential energy

U_m = stored energy in material removed

U_c = increase in stored strain energy in the surrounding rock mass

W_r = energy released.

The terms on the left side of Equation 4 represent the energy entering the system and those on the right side represent how the energy is used. For elastic conditions these terms are also inter-related (2).

$$W_t = 2(U_1 + U_m) \qquad \text{Eq 5}$$

$$W_r = U_1 + U_m = \tfrac{1}{2} W_t \qquad \text{Eq 6}$$

$$U_c = U_1 + 2U_m \qquad \text{Eq 7}$$

where, U_1 = stored strain energy in the surrounding rock mass due to the increase in stress.

There are a number of ways in which energy can be released:

$$W_r = U_m + W_s + W_k \qquad \text{Eq 8}$$

The stored energy in the material removed, U_m, is obviously released and the compression of the backfill will also absorb energy, W_s. The remainder is liberated as kinetic or seismic energy, W_k, producing oscillations in the rock mass. It can be envisaged that when a rock fails the stored strain energy, U_m, is used up in fracturing the rock non-violently. It is the seismic energy, W_k, which determines the violence of the failure and results in damage to mine openings and if large enough will produce rockbursts.

From the relationships in Equations 4 to 8 it is only necessary to calculate W_t, U_m and W_s and the other energy components can be determined.

For a thin slot the change in potential energy is expressed by:

$$W_t = S_o \, \Delta V \qquad \text{Eq 9}$$

where, ΔV = change in volumetric convergence.

This volumetric convergence can be readily obtained by integrating Equation 1 between stope limits.

The stored strain energy in the material removed in each cut can be obtained from the perpendicular stresses acting on this material just prior to removal. The stress, σ, profile into the roof can be expressed by (5):

$$\sigma = \frac{x\ S_o}{\sqrt{x^2 - a^2}} \qquad \text{Eq 10}$$

and,

$$U_m = \Sigma \frac{\sigma^2(1 - \nu^2)h}{2E} \qquad \text{Eq 11}$$

where, h = stope width.

Equation 10 predicts infinite stress on the stope back ($x = a$) which is unrealistic. The stored energy, U_m, can best be estimated by calculating the stress, σ, at depths of 0.5, 1.5 and 2.5 m, then summing the energies over successive 1 m slices.

The energy absorbed by the backfill can be expressed by:

$$W_s = \frac{\Delta V_f^2\ E_f}{2L\ h(1 - \mu^2)} \qquad \text{Eq 12}$$

where, V_f = volumetric compression of backfill

E_f = deformation modulus of backfill

L = height of backfill

μ = Poisson's ratio of backfill

$L \times h$ = volume of backfill per unit length along strike.

As an example the properties of the backfill are taken as E_f = 300 MPa (0.4% that of the rock) and μ = 0.1. The various energy components at each cut are listed in Tables 1 and 2 for 'uppers' and 'breasting' cut-and-fill, respectively and the released energy components are plotted in Fig. 4 for each cut. As can be seen the energy absorbed by the backfill, W_s, is minimal in the first few cuts (up to cuts 9 or 10), but then increases rapidly for the last few cuts. This reduces the energy which otherwise would be liberated as seismic energy, W_k. On the 13th cut, 23% of the released energy is absorbed in the backfill with 'breasting' techniques compared to 15% with 'uppers'. The ratio W_k/W_r in Tables 1 and 2 is generally referred to as the 'seismic efficiency'

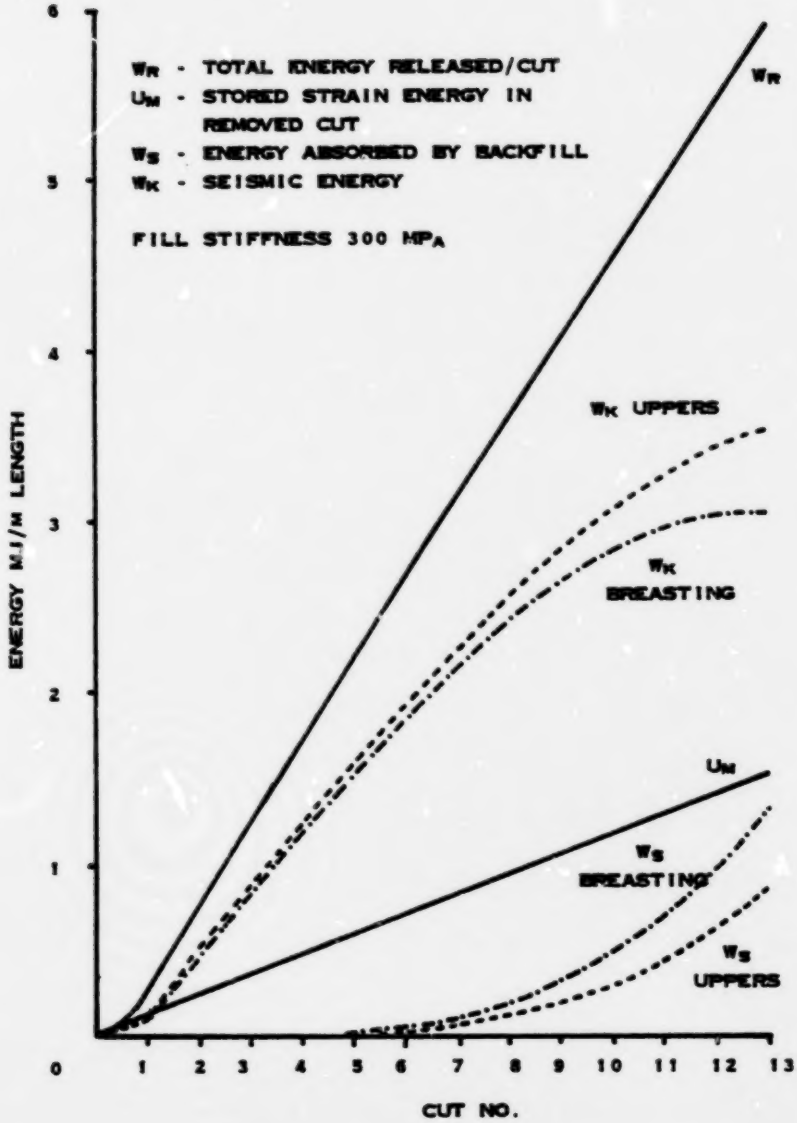

Fig. 4 - Energy release components.

Table 1 - Energy components in 'uppers' cut-and-fill

Cut No.	Stope Ht, m	Energy Components in MJ/m length W_t	U_m	U_c	W_r	W_s	W_k	$\frac{W_s}{W_r}$	$\frac{W_k}{W_r}$
1	3	0.50	0.15	0.40	0.25	0	0.10	0	40%
2	6	1.50	0.25	1.00	0.75	0	0.50	0	67%
3	9	2.46	0.35	1.58	1.23	<.01	0.88	0	72%
4	12	3.46	0.49	2.24	1.73	<.01	1.24	0	72%
5	15	4.42	0.60	2.81	2.21	.01	1.60	0.4%	72%
6	18	5.38	0.72	3.41	2.69	.03	1.94	1.1%	72%
7	21	6.28	0.84	3.98	3.14	.07	2.23	2.2%	71%
8	24	7.26	0.95	4.58	3.63	.12	2.56	3.3%	71%
9	27	8.20	1.08	5.18	4.10	.20	2.82	4.9%	69%
10	30	9.12	1.19	5.75	4.56	.30	3.07	6.6%	67%
11	33	10.04	1.30	6.32	5.02	.45	3.27	9.0%	65%
12	36	10.94	1.41	6.88	5.47	.63	3.43	11.5%	63%
13	39	11.82	1.53	7.44	5.91	.86	3.52	14.6%	60%

W_t = change in potential energy

U_m = stored strain energy in material removed from cut

U_c = increase in stored strain energy in surrounding rock mass

W_r = energy released

W_s = energy absorbed by backfill

W_k = seismic energy

W_s/W_r = backfill efficiency

W_k/W_r = seismic efficiency

Table 2 - Energy components in 'breasting' cut-and-fill

Cut No.	Stope Ht, m	Energy Components in MJ/m length W_t	U_m	U_c	W_r	W_s	W_k	$\frac{W_s}{W_r}$	$\frac{W_k}{W_r}$
1	3	0.50	0.15	0.40	0.25	0	0.10	0	40%
2	6	1.50	0.25	1.00	0.75	<.01	0.50	0	67%
3	9	2.46	0.35	1.58	1.23	<.01	0.88	0	72%
4	12	3.46	0.49	2.24	1.73	.01	1.23	0.6%	71%
5	15	4.42	0.60	2.81	2.21	.04	1.57	1.8%	71%
6	18	5.38	0.72	3.41	2.69	.08	1.89	3.0%	70%
7	21	6.28	0.84	3.98	3.14	.14	2.16	4.5%	69%
8	24	7.26	0.95	4.58	3.63	.23	2.45	6.3%	67%
9	27	8.20	1.08	5.18	4.10	.36	2.66	8.8%	65%
10	30	9.12	1.19	5.75	4.56	.53	2.84	11.6%	62%
11	33	10.04	1.30	6.32	5.02	.74	2.98	14.7%	59%
12	36	10.94	1.41	6.88	5.47	1.01	3.05	18.5%	56%
13	39	11.82	1.53	7.44	5.91	1.34	3.04	22.7%	51%

and it peaks on the 3rd or 4th cuts, then declines. However, the absolute value of seismic energy, and hence the rockburst potential, increases with each cut, although the magnitude of seismic energy does appear to peak on the 12th cut in breasting cut-and-fill.

This analysis over-estimates the seismic energy released in 'breasting' compared to 'uppers' cut-and-fill. In the latter method, usually half the stope length is blasted down at one time and the geometrical configuration is similar to the two dimensional situation analyzed. In 'breasting' cut-and-fill only sections 2 to 3 m along strike are taken down at one time. In this case the stored strain energy, U_m, in each section will be higher than that calculated. Since the energy absorbed by the backfill will be the same the seismic energy released will be correspondingly reduced.

DISCUSSION

The results given so far are specific to a given set of conditions regarding depth, stope width, elastic modulus of the rock mass and the deformation modulus of the backfill. From the Equations given previously each parameter can be altered in turn (as an example either doubled or halved) and the effect on convergence utilization and energy balance determined.

Using Equation 1, doubling the stope width will have no effect on the convergence distribution or its utilization in compressing the backfill. Doubling the depth or halving the elastic modulus of the rock mass will double the convergence, but the percentage utilization as shown in Fig. 3 will remain the same for both mining methods.

The effect of changing the parameters on the energy balance is given in Table 3 for the 13th cut in both mining methods. Doubling the stope width has no effect on the change in potential energy, W_t, it doubles the stored strain energy, U_m, and halves the energy absorbed by the backfill, W_s. The

Table 3 - Effect of changing parameters on energy components for 13th cut in uppers and breasting cut-and-fill.

Parameter Changed	Mining Method	Energy Components in MJ/m							
		W_t	U_m	U_c	W_r	W_s	W_k	$\frac{W_s}{W_r}$	$\frac{W_k}{W_r}$
Original	Uppers	11.82	1.53	7.44	5.91	.86	3.52	14.6%	60%
	Breasting					1.34	3.04	22.7%	51%
Double Stope Width	Uppers	11.82	3.06	8.97	5.91	.43	2.42	7.3%	41%
	Breasting					.67	2.18	11.3%	37%
Half Rock Elastic Modulus	Uppers	23.64	3.06	14.88	11.82	1.72	7.04	14.6%	60%
	Breasting					2.68	6.08	22.7%	51%
Double Depth	Uppers	47.28	12.24	35.88	23.64	1.72	9.68	7.3%	41%
	Breasting					2.68	8.72	11.3%	37%
Double Fill Stiffness	Uppers	11.82	1.53	7.44	5.91	1.72	2.66	29%	45%
	Breasting					2.68	1.70	45%	29%

energy released, W_r, remains the same, but a higher proportion is removed as stored strain energy, U_m, so that the seismic energy, W_k, is reduced.

Halving the elastic modulus of the wall rocks (note the orebody is still considered as rigid) doubles the change in potential energy, W_t, the stored strain energy, U_m, and the energy absorbed by the backfill, W_s. The energy released, W_r, is also doubled as is the seismic energy, W_k.

Doubling the depth quadruples the change in potential energy, W_t, and the stored strain energy, U_m, and doubles the energy absorbed by the backfill, W_s. The released energy, W_r, is also quadrupled and the seismic energy, W_k, is increased.

Doubling the deformation modulus of the backfill also doubles the energy it absorbs, W_s. The other energy components, W_t, U_m, U_c and W_r remain the same (in actual fact there will be an interaction and W_t and U_m will be decreased by a small amount). In this case there is a substantial reduction in the seismic energy released, W_k, and in breasting cut-and-fill more energy is absorbed by the backfill (45%) than is released seismically (29%). Figure 5 shows the energy release components after each cut for both mining methods. In fact the seismic energy component, W_k, peaks and subsequently declines after the 9th cut in breasting and the 11th cut in uppers cut-and-fill.

The results of this investigation suggest the following with regard to rockbursts:

a) uppers cut-and-fill longitudinal stopes are more prone to rockbursts than breasting cut-and-fill;

b) narrow longitudinal stopes are more prone to rockbursts than wide stopes;

c) stopes where the orebody has a higher elastic modulus than the surrounding wall rocks are more prone to bursting than the reverse;

d) stopes at greater depth are more prone to bursting;

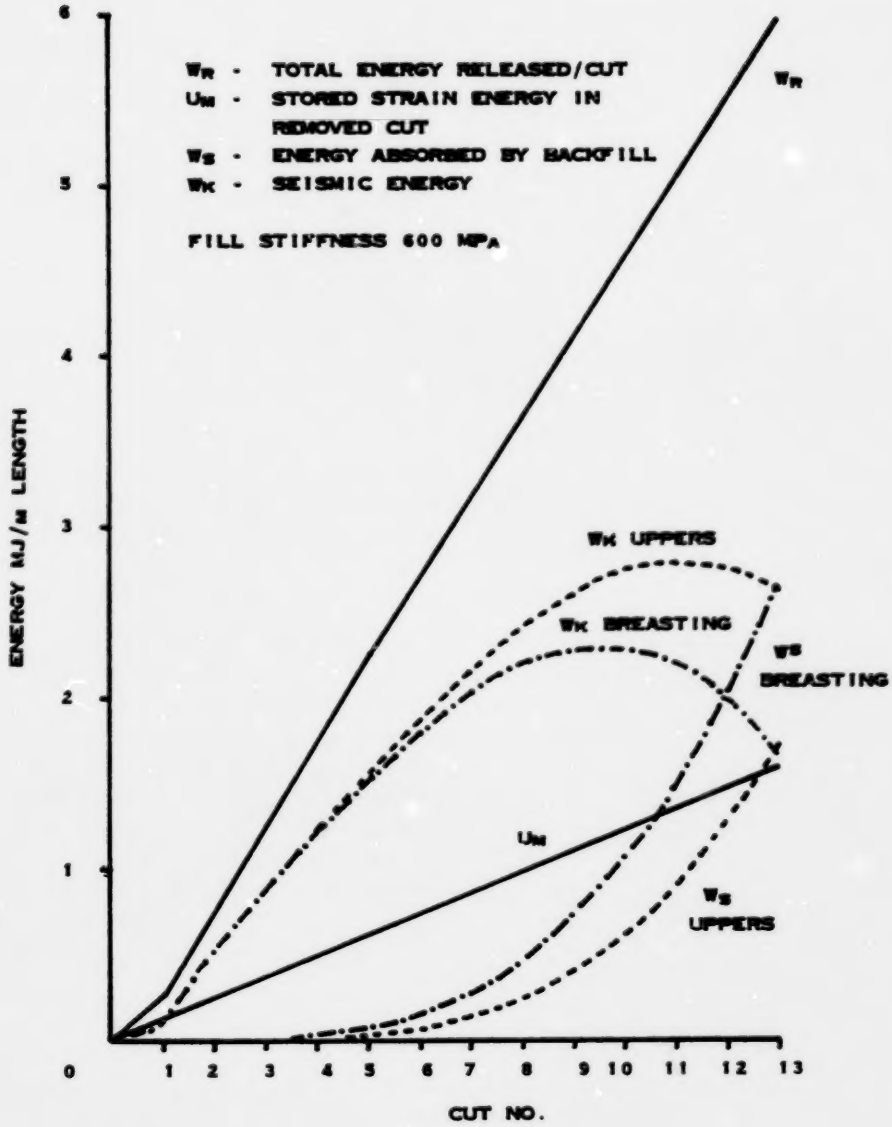

Fig. 5 - Energy release components with stiff backfill.

e) stopes with unconsolidated backfill are more prone to bursting than those with cemented backfill (higher deformation modulus).

Some of these observations are self-evident (i.e., incidents of rockbursts increase with depth) whereas others (i.e., stoping width and elastic modulus of wall rocks) are less obvious and need to be confirmed by experience in the mines.

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